DYNAMICS AND CONTROL OF THE JOVIAN MOON TOUR SPACECRAFT[1]

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Extended Abstract

NASA is developing plans for an ambitious mission to orbit three planet-sized moons of Jupiter -- Callisto, Ganymede and Europa -- which may harbor vast oceans beneath their icy surfaces.T he Jovian Moon Tour mission has two main objectives: 1) To explore the three icy moons of Jupiter - Callisto, Ganymede,a nd Europa - and investigate their makeup, their history and their potential for sustaining life; and 2) To develop a nuclear reactor and show that it can be processed safely and operated reliably in deep space for long-duration deep space exploration. Because the proposed mission requires the development and testing of many new technologies, the mission would not launch until 2011 or later. As the mission is currently proposed, a heavy lift launch vehicle would lift the spacecraft into high Earth orbit. The ion-propulsion thrusters would spiral the spacecrafta way from Earth and then on its trip to Jupiter. After entering orbit around Jupiter, thes pacecraft would orbit Callisto, then Ganymede, and finally Europa. The intensity of the radiation belts at Europa limits how long a spacecraft's electronics are able to operate in orbit around Europa, even with advances in radiation-resistant electronics that would be used on this mission. The proposed mission would incorporate a form of electric propulsion called ion propulsion. Figure 1 depicts the spacecraft configuration.

The dynamics and control challenges presented by the Jovian Moon Tour spacecraft are described in this paper. A simulation model is described which is capable of handling the coupled orbital and attitude dynamics arising during the spiraling maneuvers of the spacecraft and the tight pointing requirements needed for science when

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in orbit around the Jovian moons. Multibody dynamic models for control of the scan platform articulation and of the spacecraft flexibility using finite elements are also described. The paper also describes the spacecraft attitude commander, attitude controller, attitude estimator, and sensor and actuator models being used to derive requirements on the hardware components. Numerical simulations of the slew to gravity gradient stabilized mode and of the nadir pointed attitude dynamics around Europa demonstrate that some of the challenges hitherto identified can be faced via computational analysis, and reasonable assessments of thep ointing performance and sensor and actuator selection can be made.
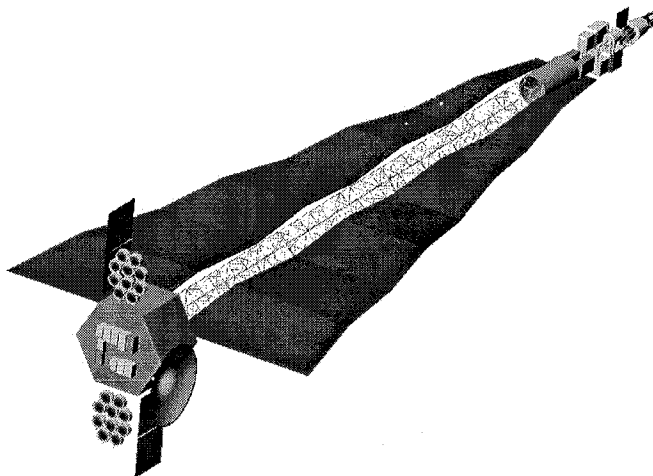

Figure 1. The Jovian Moon Tour Spacecraft.

During powered flightw ith electric propulsion (EP) using xenon ion thrusters, the combined functions of Delta-V and Thrust Vector Control will be performed by the trajectory path guidance Control Laws. Two boom mounted EP arrays (pods) each will be articulated by gimballing the pods in 2 degrees of freedom to produce pitch and yaw moments that null the spacecraft body rates and drive the net thrust vector through the spacecraft's center of mass. The gimballed EP arrays will also provide spacecraft roll axis control moments by coordinated 2 degree of freedom articulation. The TVC EP system will have the capability of performing continuous coplanar spiral pitcht urns during planetary escape and capture maneuvers. The TVC EP system will also be able to perform uncoupled turns for plane change Delta-V maneuvers. At reaching final orbit altitude the EP will be turned off and the spacecraft will be pitched up by the reaction control system to orient the reactor end to zenith in the local vertical-local horizontal coordinate system. Yaw will bea ligned with theo rbit velocity vector. Pitch will be aligned normal to the orbit plane. This will place the spacecraft in a gravity gradient stable attitude with the gimballed science module pointing to Nadir. The gravity gradient librations will be damped by the reaction wheels. High resolution imaging science drives the vehicle's pointing stability. Scientific instrumentation (cameras, plasma wave antennas, gravity experiments, magnetometer boom) are mounted on the spacecraft bus as well as on the two-dof articulated scan platform. In addition to being a massive (>20,000 kg), large (~30 meters long), deformable, spacecraft, the vehicle also hosts the

nuclear reactor and power converters (Brayton turbines spinning at more than 30,000 rpm). Fluid loops also run through the radiator shield. This means that several sources of angular momentum exist, which have to be managed accordingly in order not to corrupt thes cience measurements. Figure2 shows the spacecraft thruster map, with reaction control system thrusters and electric propulsion thrusters mounted on the ion pods, located several meters from the keel of the spacecraft.

The attitude dynamics and orbitald ynamics propagators are coupled via center of mass offsets, and because the complex orbital dynamics (highly eccentric,r etrograde,l ow altitude orbit) causes significant perturbations to the attitude. Disturbance effects considered in the dynamic model are: Europa and Jupiter Gravity Gradient, Eccentricity torque, Europa J2 and J3, Jupiter J2 and J3, 3rd body forces and torques, solarp ressure forces and torques,r eaction wheel imbalance forces and torques,a ctuator inputs.F igure 3 and Figure 4 show the 90 degree slew about the orbit normal to reach the nadirp ointed attitude around Europa, and the Attitude error (deg) and Attitude rate error (deg/s) during slew as a function of time. The simulation results verify that the selected reaction wheels are capable of stabilizing the vehicle in the Europa orbit around nadir, while the selected hydrazine thrusters have the control authority to slew the vehicle for a total of 90 degrees, without exciting the flexible body dynamics significantly, and reducing the settling time requirement to a tolerable value before science observations can take place.
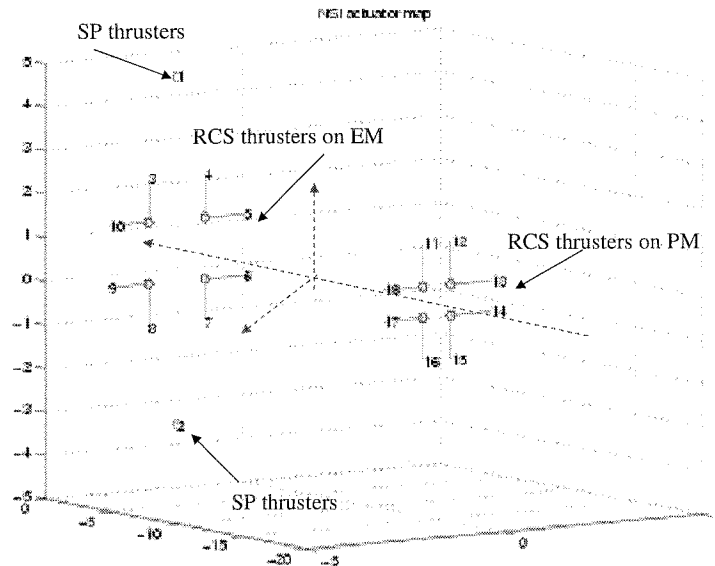

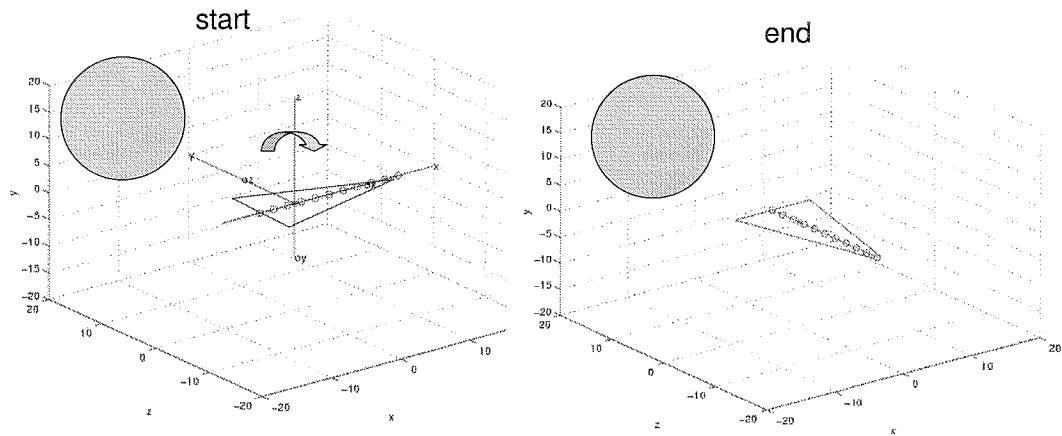Figure 2. Spacecraft thruster map (SP=electric propulsion engines,E M=engineering module, PM=propulsion module).

Figure 3. A 90 degree slew about the orbit normal to reach the nadir pointed attitude around Europa.

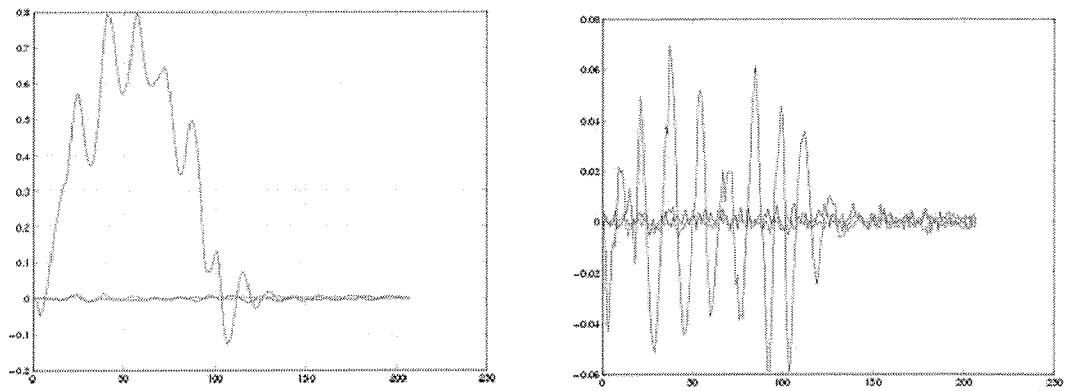attitude/rate error [deg,d eg/s vs.t ime]

Figure 4. Attitude error (deg) and Attitude rate error (deg/s) during slew as a function of time.